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(54) Method for correcting systems of coordinates in a robot having visual sensor device and apparatus therefor.

(57) The co-ordinates system correction apparatus, incorporated in a robot system having a visual sensor for measuring two or three dimensional position and posture data, corrects a visual sensor co-ordinates system and a robot co-ordinates systems. The apparatus corrects the co-ordinates systems by means of a correction of parameters representing a relationship between the co-ordinates systems. The parameter correction is caused by calculating parameter errors from a deviation between calculated position and posture data and measured position and posture data.

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FIG. 7

MOVE ROBOT TO
A DESIRED POSITION
$\overline{X}$ AND POSTURE $\overline{T}$ — 101

IMAGE
INPUT

MEASURE POSITION X''
AND POSTURE T'' OF
ROBOT VIEWED FROM
STATIONARY SENSOR

OBTAIN CALCULATED
POSITION X' AND POSTURE
T' OF ROBOT IN
STATIONARY SENSOR
CO-ORDINATES SYSTEM — 104

CORRECT PARAMETERS
ON THE BASIS OF
CALCULATED
PARAMETER ERRORS

CALCULATE PARAMETER
ERRORS FROM DEVIATIONS
BETWEEN $\overline{X}$ AND X'', AND
BETWEEN $\overline{T}$ AND T'' — 105

METHOD FOR CORRECTING SYSTEMS OF COORDINATES

IN A ROBOT HAVING VISUAL SENSOR DEVICE

AND APPARATUS THEREFOR

1 BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a control
means for a robot having a visual sensor device for
5 measuring a position and posture of an object in a two-
or three-dimension, and more particularly to a co-
ordinates system correction method and apparatus in which
deviations between a visual co-ordinates system and a
robot co-ordinates system are corrected whereby the
10 operation of the robot with the visual sensor device may
be carried out with high accuracy.

DESCRIPTION OF THE PRIOR ART

In general, environmental data from a visual
sensor are defined by a proper co-ordinates system fixed
15 to the visual sensor. This is because the position and
posture of an object are detected as the position and
posture of the object in the proper co-ordinates system
fixed to the visual sensor. For instance, Japanese Patent
Publication No. 36374/75 discloses a method for measuring
20 a position of an object by using a television camera in
a triangular surveying manner. Also, in this case, the
position of the object is known by using a co-ordinates
system related to the television camera in accordance
with the obtained video signals.

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1   On the other hand, it is convenient for carrying

out various works that the robot works are defined by the

movements of a tool mounted on a wrist of the robot.

Therefore, it is desirable that the movement of the tool

5   is defined in a proper co-ordinates system fixed to the

wrist.

Also, in the case where characteristics of the

robot per se, such as, for example, a speed command value

of the robot are desired to be calculated on the basis of

10   the co-ordinates system proper to the robot body.

Thus, it is desirable to use the co-ordinates

systems proper to the wrist and the body of the robot

and the visual sensor, respectively, in order to control

the operations of the wrist, the body and the visual

15   sensor. However, in the prior art, almost no attempt

has been made to adopt the respective co-ordinate systems.

Thus, in the conventional robot control system,

the respective co-ordinates systems have not been used.

Therefore, the most preferable co-ordinates system has

20   not always been used for the respective structural

components.

In this connection, in the conventional robot

system having a visual sensor, specific data types

corresponding to the respective visual sensor components

25   have been used whereby the data are represented to

variously drive the robot. Therefore, it is necessary

to provide various data types for the various visual

sensor components and prepare various soft wares for

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1 driving the robot. Namely, if, for example, the co-ordinates

system for the visual sensor device is solely used, even

if the same robot body and wrist are used, it is necessary

to reform the overall data system for the co-ordinates

5 system of the visual sensor device. Further, in the prior

art, the specific data system for the various visual

sensor units is used. As a result, upon controlling the

robot, such a difficulty would be encountered that a

command signal for the sensor feedback control in a stand-

10 ardized manner with the robot language is given.

Also, in the prior art, in the case where the

robot is operated by use of the visual sensor, a planar

binary or multivalue image is recognized by the visual

sensor and the handling is carried out in accordance with

15 such a recognition. Therefore, it is only possible to

handle a planar object having a constant posture. At

this time, it is sufficient to consider the parallel

movement on a plane and the rotation in the plane as

errors between the co-ordinates system of the robot and

20 the co-ordinates system of the visual sensor as shown in

USP 3,986,007, and it is relatively easy to correct the

co-ordinates system. Such a correction is carried out

in a recent planar visual sensor device which is available

on the market. However, as the handling operation of the

25 robot is increased and a object having complicated shape

must be handled, it becomes necessary to recognize a

three-dimensional object having a non-fixed position and

posture as well as a planar object. In order to meet

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1 this requirement, there has been proposed a three-
dimensional recognition method using a dual visual sensor
or distant image. In such a three-dimensional visual
sensor, it is necessary to correct spacial errors be-
5 tween the co-ordinates systems of the robot and of the
visual sensor. However, such a technique has never been
proposed or realized.

SUMMARY OF THE INVENTION

An object of the present invention to provide
10 a co-ordinates system correction method capable of
effectively utilizing data from a visual sensor means by
using the respective co-ordinates systems for the respec-
tive structural components and an apparatus for carrying
out the same.

15 Another object of the invention is to provide
a co-ordinates system correction apparatus capable of
readily coping with the position change of the visual
sensor device and/or with the replacement of the visual
sensor device.

20 Still another object of the invention is to
provide a co-ordinates system correction method and
apparatus capable of obtaining with ease and high accuracy
a spacial relationship between the visual sensor co-
ordinates system and at least one of the co-ordinates
25 systems of the robot body and the robot hand.

In order to attain the above-mentioned objects,
according to the invention there is provided a co-ordinates

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1   system correction apparatus in which a co-ordinates

system is setted in at least one of robot body and a

robot hand, the apparatus comprising visual sensor means

to which a proper co-ordinates system is setted, means

5   for detecting a position and/or posture of the object

in the co-ordinate system in the visual sensor means, and

parameter storing means for storing parameters determin-

ing a relationship between the co-ordinates system of

the visual sensor means and at least one of the co-

10   ordinates systems of the robot body and the robot hand,

wherein by using the co-ordinates transformation parameters,

the position and/or posture of the object in the co-

ordinates system of the visual sensor means are trans-

formed into one in the co-ordinates system of the robot

15   hand and/or the co-ordinates system of the robot body,

or transformed into one in the co-ordinates system of the

robot body and further transformed into one in the co-

ordinates system of the robot body.

     According to the present invention, transformation

20   parameters are established in the three co-ordinates

systems of the visual sensor means, the robot hand, and

the robot body (or in the two co-ordinates systems if the

co-ordinates systems of the robot hand and the robot

body are the same), so that the environmental data in

25   the proper co-ordinates system established in the visual

sensor means may be used in other co-ordinates system.

Therefore, it is advantageous that the respective co-

ordinates systems may be used for the respective structural

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1 components. In addition, the environmental data obtained

from the visual sensor means may be effectively used.

According to another aspect of the invention,

a plural kinds of the co-ordinates transformation para-

5 meters are set and stored in the storing means whereby

even if the visual sensor means is replaced by another

visual one, the co-ordinates transformation parameters

corresponding thereto may be assigned. In accordance

with the specific embodiment, since plural kinds of

10 transformation parameters are prepared, any parameter

may be assigned corresponding to the various visual sensor

means. Such a various correspondence to the various

kinds of visual sensor means is actually available. It

is necessary to fix the visual sensor means anywhere in

15 the robot body. However, the visual sensor means is

not limited to a single visual sensor means, and it is

general that the position where the visual sensor means

is fixed is different in accordance with an object to

be handled. Therefore, it is necessary to install the

20 visual sensor means to a different position in accordance

with the respective mounting positions and to use dif-

ferent visual sensor means. It is therefore preferable

to assign the corresponding parameters in accordance

with the respective positions. As in the embodiment of

25 the invention, if plural kinds of parameters are stored,

when the visual sensor means is replaced by new one or

changed in its position, it is possible to assigne the

parameters corresponding to the changes. This is very

1 convenient.

Also, it is necessary to measure the position
and posture of the object and direct the robot hand to
the posture direction in order to handle the object in
5 any position and posture. To meet this requirement, it
is necessary to accurately correct a deviation of the
visual sensor co-ordinates system for measuring the posi-
tion and posture of the object from the robot body or
robot hand co-ordinates system in accordance with the
10 parameters. By the way, even if the robot is moved in
accordance with the position and posture information
measured by the visual sensor device, the robot is moved
to a position and posture deviated from the practical
position and posture of the object. Therefore, by
15 utilizing this feature inversely, in the robot body and/
or robot hand co-ordinates systems, the position and
posture of the object known in advance are measured by
the visual sensor means, and it is possible to obtain
the parameters giving a relationship between the robot
20 visual sensor and the robot body or hand co-ordinates
systems from the errors between the measured values and
the calculated values. In accordance with the present
invention, by using the parameters in this manner, the
correction between the robot body or hand co-ordinates
25 system and the visual sensor co-ordinates system may be
attained.

1 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing a robot system to which one embodiment of the invention is applied;

5 Fig. 2 is a perspective view showing a co-ordinates system of a visual sensor shown in Fig. 1;

Fig. 3 is a perspective view showing a co-ordinates system fixed to the object shown in Fig. 2;

Fig. 4 is a schematic view illustrating a robot

10 system to which a three-dimensional stationary visual sensor device is fixed;

Figs. 5 and 6 are views showing a relationship between the robot co-ordinates system and the stationary visual sensor co-ordinates system;

15 Fig. 7 is a block diagram showing the functions of the components of the system shown in Fig. 4;

Fig. 8 is a view showing one robot system having a three-dimensional visual sensor;

Fig. 9 is a view showing a relationship between

20 the robot hand co-ordinates system and the robot visual sensor co-ordinates system;

Fig. 10 is a view showing a relationship between the object and the robot hand with a visual sensor; and

Fig. 11 is a block diagram showing the functions

25 of the components of the system shown in Fig. 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the invention will

1 now be described with reference to the accompanying

drawings.

In Fig. 1, there is shown a robot system provided

with a co-ordinates system correction device in accordance

5 with the preferred embodiment. Two visual devices 1 and

2 are provided in this robot system. The stationary visual

device 1 is secured to a base 5 on which a robot 3 is

installed. The wrist visual device 2 is mounted on a

wrist portion of the robot 3. The robot system shown has

10 six degrees of freedom in motion.

In this robot system, the visual devices 1 and

2 may detect a position and a posture of an object 4.

A co-ordinates system is set in a robot body. More

specifically, stationary co-ordinates XYZ is fixed in a

15 stationary portion between the robot 3 and the base 5.

Another co-ordinates system is set in the wrist portion

of the robot 3 and is, in particular, composed of co-

ordinates $x_h y_h z_h$ of a hand 6. On the other hand, proper

co-ordinates systems are established for the visual

20 devices 1 and 2, respectively. Namely, a co-ordinates

system $x_1 y_1 z_1$ is fixed for the stationary visual device

1 and a co-ordinates system $x_2 y_2 z_2$ is fixed for the wrist

visual device 2.

When the object 4 are detected on the basis

25 of the co-ordinates systems $x_1 y_1 z_1$ and $x_2 y_2 z_2$ by the

visual devices 1 and 2 through an image processor 8, the

data from the visual devices 1 and 2 on the basis of the

visual device co-ordinates systems are transformed into

1 the data on the basis of the co-ordinates systems of the robot 3 through parameters giving relationships between the co-ordinates systems of the visual devices 1 and 2, and the stationary co-ordinates XYZ and the co-ordinates

5 x_h, y_h, z_h of the hand 6. Thus, the data detected by the visual devices 1 and 2 on the basis of their own co-ordinates systems are transformed into the data on the basis of the co-ordinates systems of the robot body and of the wrist of the robot. The robot operates on the

10 basis of such transformed data. In this manner, the structural components can desirably operate on the basis of the respective co-ordinates systems. The above-described parameters are stored in a parameter storing means incorporated in a robot control unit 7.

15 In this embodiment, a plural sets of parameters are provided and stored in the parameter storing means so as to readily cope with the position changes of the visual devices and/or the replacement of the visual devices.

20 The construction and the operation of the embodiment will now be described in more detail.

As described above, in this embodiment, a visual sensor system includes two visual devices 1 and 2. The stationary visual device 1 is fixed to the base 5

25 and the wrist visual device 2 is mounted on the wrist portion of the robot 3. Each of the visual devices is composed of, e.g. a camera having a slit light source. The stationary visual device 1 is a two- or three-

1   dimensional visual sensor and can recognize the position

and the posture of the object 4. For instance, if the

stationary visual device 1 is a two-dimensional visual

sensor, a position $\vec{p}$ of the object 4 in the co-ordinates

5   system fixed to the visual device 1 as shown in Fig. 2 is

defined by the components p_{x1}, p_{y1}, p_{z1} of the x_1, y_1, z_1

axes and is expressed in the following equation (1).

$$\vec{p} = p_{x1}\, \vec{i}_1 + p_{y1}\, \vec{j}_1 + p_{z1}\, \vec{k}_1 \qquad \ldots\ldots \text{(1)}$$

where $\vec{i}_1$, $\vec{j}_1$, and $\vec{k}_1$ are the unit vectors in parallel to

the x_1, y_1 and z_1 axes, respectively. When the stationary

10   visual device 1 is the two-dimensional sensor, in

general, a direction of the z_1 axis is determined by the

mounting position of the visual sensor and the component

p_{z1} is a constant. On the other hand, the posture of

the object 4 is expressed by cosine components of the

15   two axes fixed thereto and intersected at a right angle

with each other as shown in Fig. 3. The cosine compo-

nents are given by unit vectors $\vec{f}$ and $\vec{g}$. When the object

4 shown in Fig. 3 is viewed from above the axis $\vec{f}$ with

the two-dimensional visual sensor, the posture is given

as follows.

$$\vec{f} = \vec{k}_1 \qquad\qquad \ldots\ldots \text{(2)}$$

$$\vec{g} = g_{x1}\, \vec{i}_1 + g_{y1}\, \vec{j}_1 \qquad\qquad \ldots\ldots \text{(3)}$$

If the stationary visual device 1 is of the three-dimensional type, it is possible to recognize any positions and postures of the object. In this case, the 9 (nine) parameters of p_{x1}, p_{y1}, ..., g_{y1}, and g_{z1} in the following equations may be detected.

$$\vec{p} = p_{x1} \vec{i}_1 + p_{y1} \vec{j}_1 + p_{z1} \vec{k}_1 \qquad \cdots\cdots (4)$$

$$\vec{f} = f_{x1} \vec{i}_1 + f_{y1} \vec{j}_1 + f_{z1} \vec{k}_1 \qquad \cdots\cdots (5)$$

$$\vec{g} = g_{x1} \vec{i}_1 + g_{y1} \vec{j}_1 + g_{z1} \vec{k}_1 \qquad \cdots\cdots (6)$$

Since the stationary visual device 1 is fixed to the base 5, the relationship between to co-ordinates system of the stationary visual device 1 and the stationary co-ordinates XYZ is unchangeable a fixed manner, and then the cosine components (p_X, p_Y, p_Z), (f_X, f_Y, f_Z), (g_X, g_Y, g_Z) of $\vec{p}$, $\vec{f}$, $\vec{g}$ in the co-ordinates XYZ are given by the following relationship with using the data from the visual device 1.

$$\begin{pmatrix} 1 & 0 & 0 \\ p_X & f_X & g_X \\ p_Y & f_Y & g_Y \\ p_Z & f_Z & g_Z \end{pmatrix} = A \begin{pmatrix} 1 & 0 & 0 \\ p_{x1} & f_{x1} & g_{x1} \\ p_{y1} & f_{y1} & g_{y1} \\ p_{z1} & f_{z1} & g_{z1} \end{pmatrix} \qquad \cdots\cdots (7)$$

where A is a matrix of 4 x 4 and its all elements are constants.

In the same manner, the wrist visual device 2 mounted on the wrist portion of the robot may detect the position and posture components (p_{x2}, p_{y2}, p_{z2}), (f_{x2}, f_{y2}, f_{z2}), (g_{x2}, g_{y2}, g_{z2}) of the object on the basis of the characteristic co-ordinates system $x_2\ y_2\ z_2$ fixed in the visual device 2. Since the visual device 2 is fixed to the wrist of the robot, the co-ordinates system of the visual device 2 is in an unchangeable relation with the co-ordinates x_h, y_h, z_h of the hand 6 also fixed to the wrist portion. The data of the position and posture of the object from the wrist visual device 2 are transformed into the data on the basis of the hand co-ordinates system through the following relationship.

$$
\begin{pmatrix}
1 & 0 & 0 \\
p_{xh} & f_{xh} & g_{xh} \\
p_{yh} & f_{yh} & g_{yh} \\
p_{zh} & f_{zh} & g_{zh}
\end{pmatrix}
= B
\begin{pmatrix}
1 & 0 & 0 \\
p_{x2} & f_{x2} & g_{x2} \\
p_{y2} & f_{y2} & g_{y2} \\
p_{z2} & f_{z2} & g_{z2}
\end{pmatrix}
\quad \dots \text{(8)}
$$

where B is a matrix of 4 x 4 and its all elements are constants.

As described above, in this embodiment, the relationship between the co-ordinates system x_1, y_1, z_1 of the stationary visual device 1 and the stationary co-ordinates system X Y Z is given by the parameters determined by the matrix A. Also, the relationship between the co-ordinates system x_2, y_2, z_2 of the wrist visual device 2 and the co-ordinates system x_h, y_h, z_h

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1 of the hand 6 is given by the parameters determined by
the matrix B. Therefore, the data which the visual
devices 1 and 2 recognize with their own co-ordinates
systems, respectively, are transformed into the data on

5 basis of the co-ordinates systems of the robot 3 and the
hand 6 fixed to the wrist of the robot 3 through the above-
described parameters. The robot operates on such trans-
formed data. These parameters are stored in the parameter
storing means of the robot control unit 7.

10 The embodied apparatus with such a construction
will operate as follows with respect of the control of
the robot.

For instance, when it is assumed that the hand
6 of the robot is controlled to be positioned in the

15 same place as the position and the posture of the object
are recognized by the visual sensors. In this case,
it is preferable that the position and posture $\vec{p}$, $\vec{f}$, $\vec{g}$
of the hand 6 be given by the stationary co-ordinates
system. Therefore, when the stationary visual device 1

20 is used, the data from the visual device 1 are multiplied
by the matrix A of parameter and are transformed into
the data on the stationary co-ordinates. This makes it
possible to control the hand 6 by means of usage of such
transformed data. When the wrist visual device 2 is

25 used, in the same manner, the data from the visual device
2 is used, in the same manner, the data from the visual
device 2 are multiplied by the matrix B of parameter
and are transformed into the data on the hand co-ordinates

1 system. In this case, the transformed data may be further

transformed into the data on the stationary co-ordinates

system by using another parameters. These another

parameters may be expressed by a matrix C, the matrix C

5 is of 4 x 4 type and its elements are functions of 6 (six)

displacements of a kinematic pair θ_1, θ_2, $\cdots$, θ_6, i.e.

$c_{ij} = f_{ij}$ (θ_1, θ_2, $\cdots$, θ_6). From the values of $\vec{p}$, $\vec{f}$ and

$\vec{g}$ thus transformed into the stationary co-ordinates

system, the displacements of the kinematic pair θ_{1f}, θ_{2f},

10 $\cdots$, θ_{6f} are calculated, each of which corresponds to

the respective transformed values. Then, an actuator for

driving the kinematic pair is controlled so that each

dispacement of the respective pairing elements becomes

the corresponding calculated value.

15   An explanation has been made as to the example

of a robot system having two visual sensors. However,

any number of the visual sensors may be used as far as

parameters determining a relationship between the co-

ordinates fixed to each visual sensor and the robot co-

20 ordinates are defined. In this case, if the visual

sensors are numbered and then the number of a desired

visual sensor is called out by a robot language or the

like, the control unit 7 generates a drive signal to the

desired visual sensor. Then, the data from visual

25 sensors are multiplied by a matrix (parameters) stored

in advance and corresponding to the called visual sensor,

so that the data for controlling the robot may be obtained.

As described above, in the co-ordinates system

1   correction apparatus in accordance with this embodiment,

since the visual devices 1 and 2 are provided with the

respective co-ordinates system therefor and the

relationships between the sensor co-ordinates systems

5   and the robot co-ordinates systems are determined by

the matrixes, the same drive soft ware may control the

robot in accordance with each signal of the sensors even

for the robot system having a plurality of visual sensors.

Therefore, it is possible to standardize the drive soft

10   ware. Also, if the matrices each corresponding to

the respective sensors are stored in the control unit 7

in advance, it is possible to carry out the feedback

control of the robot simply by calling the desired

sensor number in terms of the robot language. A compli-

15   cated robot language command may not be required. Further,

if the parameters for data transformation are represented

in a matrix form, it is possible to attain a high speed

calculation through an array processor. If the matrix

is simple, it is of course possible to make the data

20   transformation through a particular sub-routine.

        In the preceding embodiments, although there

is not shown a specific method for obtaining the trans-

formation matrixes A or B in the case where the visual

device 1 or 2 is of a three-dimensional visual sensor

25   type, the co-ordinates system correction apparatus in

accordance with the present invention may be used for

that case. A method for obtaining the matrix A will

now be described in accordance with another embodiment.

Fig. 4 is an illustration of one embodiment showing a parameter measuring method in relation to a three-dimensional visual sensor. Fig. 5 is a schematic view showing a relationship between the robot and the stationary visual sensor. Fig. 6 shows a relationship between the co-ordinates systems of the robot and the stationary visual sensor. Fig. 7 is a block diagram illustrating functions of components of the embodiment shown in Fig. 4.

In these figures, a reference numeral 1 designates a stationary visual device or sensor fixedly mounted onto a base 5 on which a robot 3 is installed. The robot 3 is provided at a distal end portion thereof with a hand 6. The stationary visual device 1 and the robot 3 are associated with a robot control unit 8, an image processor 8, and a parameter calculator 9.

It is assumed, as shown in Fig. 5 that the $\vec{O}_R$ is an origin of the robot co-ordinates system comprising the axes of $\vec{x}_R$, $\vec{y}_R$ and $\vec{z}_R$, and the $\vec{O}_v$ is an origin of the stationary visual sensor co-ordinates system comprising the axes of $\vec{x}_v$, $\vec{y}_v$ and $\vec{z}_v$, the relationship between the robot co-ordinates system and the stationary visual sensor co-ordinates system may be expressed by the following equations:

$$\vec{O}_v = \vec{O}_R + L_x \vec{x}_v + L_y \vec{y}_v + L_z \vec{z}_v$$

$$= \vec{O}_R + \vec{L} \begin{bmatrix} \vec{x}_v \\ \vec{y}_v \\ \vec{z}_v \end{bmatrix} \qquad \ldots \ (9)$$

$$
\begin{bmatrix} \vec{x}_V \\ \vec{y}_V \\ \vec{z}_V \end{bmatrix} = M_\gamma\, M_\beta\, M_\alpha \begin{bmatrix} \vec{x}_R \\ \vec{y}_R \\ \vec{z}_R \end{bmatrix} = M \begin{bmatrix} \vec{x}_R \\ \vec{y}_R \\ \vec{z}_R \end{bmatrix} \quad \dots\, (10)
$$

1 where $\vec{L} = (L_x,\ L_y,\ L_z)$ is a vector representing the dis-
placement from the origin $\vec{O}_R$ of the robot co-ordinates
system to the origin $\vec{O}_V$ of the stationary visual sensor
co-ordinates system, and M_γ, M_β, and M_α are matrixes

5 representing the three rotational displacements between
the co-ordinate systems. These matrixes are expressed
as follows, when angles of rotation α, β, and γ are
selected as shown in Fig. 6:

$$
M_\alpha = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix}, \quad M_\beta = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix},
$$

$$
M_\gamma = \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \dots\, (11)
$$

The robot control unit 7 commands the robot 3 to

10 move to the position $\vec{X} = (x,\ y,\ z)$ and posture $\vec{f} = (f_x,$
$f_y,\ f_z)$ in terms of the robot co-ordinates system. If
the parameters L_x, L_y, L_z, α, β, and γ are the same
values as the designed one and include no error, the
robot must be moved to the following points:

$$\vec{X} = x\,\vec{x}_R + y\,\vec{y}_R + z\,\vec{z}_R + \vec{O}_R \qquad \dots\ (12)$$

$$\vec{f} = f_x\,\vec{x}_R + f_y\,\vec{y}_R + f_z\,\vec{z}_R \qquad \dots\ (13)$$

1 To the contrary, in case that these position and the posture are calculated with using the data from the stationary visual sensor 1 and the calculated position and posture are expressed as $\vec{X}' = (x', y', z')$, $\vec{f}' =$
5 $(f_{x'}, f_{y'}, f_{z'})$.

$$\vec{X}' = x'\,\vec{x}_v + y'\,\vec{y}_v + z'\,\vec{z}_v + \vec{O}_v \qquad \dots\ (14)$$

$$\vec{f}' = f_{z'}\,\vec{x}_v + f_{y'}\,\vec{y}_v + f_{z'}\,\vec{z}_v \qquad \dots\ (15)$$

The relationships between x, y, z and x', y', z', and between f_x, f_y, f_z and $f_{x'}$, $f_{y'}$, $f_{z'}$ are determined from the equations (9) to (11).

However, if the stationary visual sensor 1 is
10 not accurately mounted on the predetermined portion of the robot system, the errors are expressed as ΔL_x of L_x, ΔL_y, ΔL_z, $\Delta\alpha$, $\Delta\beta$, and $\Delta\gamma$. In this case, the parameters in the equations (9) to (11) become $(L_x + \Delta L_x)$, $(\alpha + \Delta\alpha)$ and the like. Therefore, even if the robot is commanded
15 to move to $\vec{X} = (x, y, z)$, $\vec{f} = (f_x, f_y, f_z)$, the robot can not reside in the position and posture $\vec{X}' = (x', y', z')$, $\vec{f}' = (f_{x'}, f_{y'}, f_{z'})$ but in $\vec{X}'' = (x'', y'', z'')$, $\vec{f}'' = (f_{x''}, f_{y''}, f_{z''})$ which are deviated from $\vec{X}'$, $\vec{f}'$. Therefore, if the respective deviations between x', y',

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1 z' and x'', y'', z'', and between $f_{x'}$, $f_{y'}$, $f_{z'}$ and $f_{x''}$, $f_{y''}$, $f_{z''}$ are measured, ΔL_x, ΔL_y, ΔL_z, $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$ may be obtained from the equations (9) to (11).

The construction and operation of the embodiment

5 shown in Fig. 4 will now be described with reference to Fig. 7.

The robot 3 is moved in accordance with the position and posture command vectors $\vec{X}$, $\vec{f}$ from the robot control unit 7 (step 101). The stationary visual sensor

10 1 picks up an image of the robot 3 after the movement thereof and feed the image information to the image processor 8 (step 102). The position and posture $\vec{X}''$, $\vec{f}''$ of the robot 3 as viewed from the stationary visual sensor 1 are measured in the image processor 8 (step 103).

15 On the other hand, the parameter calculator 9 calculates the position and posture $\vec{X}'$, $\vec{f}'$ (equations (14) and (15)) in the stationary visual co-ordinates system by using the equations (9), (10) and (11) on the basis of the command signals or vectors $\vec{X}$, $\vec{f}$ from the robot control

20 unit 7 (step 104). If the stationary visual sensor 1 is accurately mounted on the predetermined portion of the robot system, the position $\vec{X}''$ and posture $\vec{f}''$ of the robot measured by the stationary sensor 1 coinside with the calculated position $\vec{X}'$ and posture $\vec{f}'$ of the robot.

25 To the contrary, if the stationary sensor 1 is not accurately mounted on the predetermined portion of the robot system, the measured position $\vec{X}''$ and posture $\vec{f}''$ are deviated from the calculated position $\vec{X}'$ and posture

1    $\vec{f}'$ by some deviations caused by such unaccurate mounting

of the robot. Namely, the measured position $\vec{X}''$ and

posture $\vec{f}''$ have the deviations from the practical

position and posture of the robot, which are caused by

5   the parameter errors, e.g. ΔL_x. Accordingly, the correct

parameters may be obtained from the respective deviations

between $\vec{X}'$ and $\vec{X}''$, and between $\vec{f}'$ and $\vec{f}''$ (steps 105,

106).

Also, in the above-described measurement of the

10   parameters, even if the visual device is fixed to the

wrist of the robot as the visual sensor 2, the matrix B

may be obtained in the same manner.

Fig. 8 is a schematic view illustrating one

embodiment of a robot system having a three-dimensional

15   movable visual sensor, Fig. 9 shows the relationship

between the robot hand co-ordinates system and the robot

visual sensor co-ordinates system, Fig. 10 shows the

relationship between the object and the robot hand with

the visual sensor more specifically, and Fig. 11 is a

20   block diagram showing the functions of the components of

the system shown in Fig. 8.

In these figures, a reference numeral 2

designates a wrist visual sensor mounted on a distal end

portion of the robot for sensing an object 4 to be measured.

25   The other elements and components are the same as shown

in Fig. 4.

As shown in Fig. 9, the parameters to be used

upon mounting the robot wrist visual sensor 2 on the robot

1 wrist include 6 (six) parameters such as a vector $\vec{L} = (L_x,$ $L_y,\ L_z)$ representing a displacement between the origin $\vec{O}_h$ of the robot hand co-ordinates system and the origin $\vec{O}_v$ of the robot wrist visual sensor co-ordinates system,

5 and angles of rotation α, β, γ representing the respective rotational displacement between the corresponding axes of the co-ordinates systems. In this case, the relation- ships between the origin $\vec{O}_h$ of the robot hand co-ordinates system and the origin $\vec{O}_v$ of the wrist visual sensor co-

10 ordinates system, and between the axes $\vec{x}_h$, $\vec{y}_h$, $\vec{z}_h$ of the robot hand co-ordinates system and the axes $\vec{x}_v$, $\vec{y}_v$, $\vec{z}_v$ of the wrist visual sensor co-ordinates system are represented by the following equations:

$$\vec{O}_v = \vec{O}_h + L_x\,\vec{x}_h + L_y\,\vec{y}_h + L_z\,\vec{z}_h \qquad \ldots (16)$$

$$\begin{pmatrix} \vec{x}_v \\ \vec{y}_v \\ \vec{z}_v \end{pmatrix} = M_\gamma\ M_\beta\ M_\alpha \begin{pmatrix} \vec{x}_h \\ \vec{y}_h \\ \vec{z}_h \end{pmatrix} = M \begin{pmatrix} \vec{x}_h \\ \vec{y}_h \\ \vec{z}_h \end{pmatrix} , \quad M = M_\gamma\ M_\beta\ M_\alpha$$

$$\ldots (17)$$

where M_α, M_β and M_γ are the 3x3 matrixes representing the

15 rotations about $\vec{x}_h$, $\vec{y}_n$ and $\vec{z}_h$, respectively, and are given as follows:

$$M_\alpha = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix} ,$$

$$M_\beta = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix} ,$$

$$M_\gamma = \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \dots\, (18)$$

1   As shown in Fig. 10, if the normal vector fixed to the object 4 as viewed from the robot wrist visual sensor co-ordinates system is expressed as $\vec{f} = (f_x^V, f_y^V, f_z^V)$, the following equation is obtained:

$$\vec{f} = f_x^V \vec{x}_v + f_y^V \vec{y}_v + f_z^V \vec{z}_v \qquad \dots\, (19)$$

5 In order to express this vector in terms of the robot hand co-ordinates system, the vector is transformed into the following equation by expressing $\vec{x}_v$, $\vec{y}_v$, $\vec{z}_v$ by $\vec{x}_h$, $\vec{y}_h$, $\vec{z}_h$ in accordance with the equations (17) and (18):

$$\vec{f} = f_x^R \vec{x}_h + f_y^R \vec{y}_h + f_z^R \vec{z}_h \qquad \dots\, (20)$$

where the normal vector as viewed from the robot hand

10 co-ordinates system is expressed by $\vec{f} = (f_x^R, f_y^R, f_z^R)$.

      Also, when a point on the object 4 is viewed from the visual sensor co-ordinate system, if the point is viewed as $\vec{X} = (x_v, y_v, z_v)$, the following equation is given:

$$\vec{X} = x_v \, \vec{x}_v + y_v \, \vec{y}_v + z_v \, \vec{z}_v$$

.... (21)

1   If the scaling ratios of the television camera of the
robot wrist visual sensor 2 are expressed by s_x, s_y,
s_z with respect to the respective directions $\vec{x}_v$, $\vec{y}_v$, $\vec{z}_v$,
$\vec{X}$ is viewed from the robot wrist co-ordinate system,

5   and is expressed in accordance with the equation (16)
as follows:

$$\vec{X} = L_x \, \vec{x}_h + L_y \, \vec{y}_h + L_z \, \vec{z}_h + s_x \, x_v \, \vec{x}_v +$$

$$s_y \, y_v \, \vec{y}_v + s_v \, z_v \, \vec{z}_v$$

.... (22)

$\vec{x}_v$, $\vec{y}_v$, $\vec{z}_v$ in this equation are represented by $\vec{x}_h$, $\vec{y}_h$, $\vec{z}_h$
in accordance with the equations (17) and (18) and are
substituted thereby.   Then, the following equation is

10   given:

$$\vec{X} = x_h \, \vec{x}_h + y_h \, \vec{y}_h + z_h \, \vec{z}_h$$

.... (23)

If the equation (22) is thus transformed, the fixed point
as viewed from the robot wrist co-ordinate system is
positioned as $\vec{X} = (x_h, \, y_h, \, z_h)$.

As potential errors which would be generated

15   when the robot wrist visual sensor 2 is mounted on the
robot hand, errors ΔL_x, ΔL_y, ΔL_z, $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$ would be
considered with respect to L_x, L_y, L_z, α, β, γ, respectively.
When these errors would be present, the parameters in the

1 equations (16) to (18) such as L_x are replaced by $(L_x +$ $\Delta L_x)$ and the like. In this case, the equations (16) and (17) may be rewritten as follows:

$$\begin{pmatrix} \vec{O}_v \\ \vec{x}_v \\ \vec{y}_v \\ \vec{z}_v \end{pmatrix} = G \begin{pmatrix} \vec{O}_h \\ \vec{x}_h \\ \vec{y}_h \\ \vec{z}_h \end{pmatrix} \quad , \quad G = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{23} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix}$$

.... (24)

The element g_{ij} of the matrix G includes errors ΔL_x and

5 the like. If g_{ij} is known, ΔL_x, ΔL_y, ΔL_z, $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$ may be known by conducting suitable calculations.

Unless errors exist, the object 4 which resides in a position $\vec{X} = (x_v, y_v, z_v)$ and in a posture $\vec{f} = (f_x^V, f_y^V, f_z^V)$ as viewed through the robot wrist visual

10 sensor 2 may reside in a position $\vec{X} = (x_h, y_h, z_h)$ and a posture $\vec{f} = (f_x^R, f_y^R, f_z^R)$ as viewed through the robot hand co-ordinates. However, actually, due to the errors such as ΔL_x, it is measured that the object 4 resides in a position $\vec{X}' = (x_h', y_h', z_h')$ and in a posture $\vec{f}' = (f_x^{R'},$

15 $f_y^{R'}, f_z^{R'})$. By these deviations of the position and posture, the equations (16) and (17) are deformed into the equation (24). Accordingly, by measuring the deviations in position and posture, it is possible to determine the elements g_{ij} of the matrix G. If the

20 elements g_{ij} are known, the errors such as ΔL_x may be obtained.

1   The construction and operation of the specific

embodiment will now be described with reference to Figs.

8 and 11.

        The robot 3 is moved close to the fixed point

5 on the object 4 in accordance with the command signals

of the position and posture from the robot control unit

7 (step 201). Thereafter, the image information is

inputted into the robot wrist visual sensor 2 and fed to

the image processor 8 (step 202). The position and

10 posture $\vec{X}'$ and $\vec{f}'$ are measured in the image processor 8

(step 203).

        On the other hand, the position and posture of

the fixed point on the object is inputted in advance in

the parameter calculator 9 (step 204). On the basis of

15 the wrist position and posture information (step 205)

from the robot control unit 7, the position and posture

$\vec{X}$ and $\vec{f}$ of the fixed point as viewed from the robot wrist

visual sensor co-ordinates system are calculated in

accordance with the equations (16), (17) and (18) (step

20 206). Upon the calculation of $\vec{X}$, $\vec{f}$, it is made on the

basis of that there is no error in the parameters whereas

the $\vec{X}'$, $\vec{f}'$ measured by the robot wrist visual sensor 2

include the parameter errors. Therefore, the vectors $\vec{X}$

and $\vec{X}'$ and $\vec{f}$ and $\vec{f}'$ are different from each other. Then,

25 if the matrix G in the equation (24) is obtained in

accordance with $\vec{X}'$, $\vec{f}'$ (step 207), the parameters included

in the respective components of the matrix G include

errors. Accordingly, by comparing the parameters in the

1 equations (16) and (17) to the parameters in the matrix

G, it is possible to obtain the parameter errors (step

208).

As described above, in accordance with the

5 present invention, in a co-ordinate system correction

apparatus including visual sensor means for detecting

a position and/or posture of an object, the apparatus

comprises means for setting a co-ordinate system in at

least one of a robot body and a robot wrist, setting a

10 proper co-ordinate system in the visual sensor means and

detecting the position and/or posture of the object in the

co-ordinate system in the visual sensor means, and para-

meter storing means for storing parameters determining a

relationship between the co-ordinate system of the

15 visual sensor means and at least one of the co-ordinate

systems of the robot body and the robot wrist. By using

the co-ordinate transformation parameters, the position

and/or posture of the object in the co-ordinate system

of the visual sensor means are transformed into the

20 co-ordinate system of the robot wrist and the co-ordinate

system of the robot body, or otherwise into the co-ordinate

system of the robot body and further transformed into the

co-ordinate system of the robot body. Accordingly, the

respective structural elements such as the visual sensor

25 means are operated by the respective co-ordinate systems.

Thus, by the operation in a desired condition, it is

advantageous that the obtained data are effectively

utilized. Also, it is easy to carry out the co-ordinate

1 transformation with the parameters. By storing the
parameters in the parameter storing means, it is possible
to always correspond to the transformation of the data
from the visual sensor means.

5   Furthermore, according to the invention, by
preparing and using a plurality of parameters, it is
possible to correspond to the case where the visual
sensor is changed in position and another visual sensor
is used.

10   Also, it is possible to construct the robot
system so as to command the robot in a standardized manner
with a simple robot language.

      Moreover, in accordance with the present
invention, since three-dimensional mounting parameters

15 generated when the visual sensor is fixed to the robot
co-ordinates system may be obtained by moving the robot,
the following meritorious advantages can be obtained.

      (1) By obtaining the three-dimensional mounting
parameters and using them, it is possible to handle with

20 high accuracy a three-dimensional object taking any
position and posture as well as a planar object by means
of the visual sensors.

      (2) Also, the mounting parameters may be
obtained simply by measuring the object while moving the

25 robot. Accordingly, the correction work can be made
more readily than the measurement of the mounting para-
meters with a measuring tools. This leads to enhancement
in accuracy of the robot operation and in efficiency.

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1   It is apparent that the present invention is
not limited to the embodiments shown but various changes
or modification are possible for those skilled in the
art.

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CLAIMS

1.   A robot system having a visual sensor comprising:

a robot having a first co-ordinates system
provided in at least one of a robot body and a robot
hand;

a visual sensor device having a second co-
ordinates system for detecting a position and/or posture
of an object;

means for measuring parameters determining a
relationship between said second co-ordinates system and
said first co-ordinates system;

means for storing said parameters measured by
means of said measuring means; and

means for transforming a detected position and/or
posture information of the object in said second co-
ordinates system into an information in said first co-
ordinates system through said measured parameters.

2.   A robot system as claimed in Claim 1, wherein
said parameters for co-ordinates transformation includes
a plurality of sets of parameters each set corresponding to
a respective visual sensor devices whereby a corresponding
co-ordinates transformation parameter set may be assigned
even if the visual sensor device is replaced by another
visual sensor device.

3.   A robot system as claimed in Claim 2, wherein
said co-ordinates transformation parameter sets include
one for a visual sensor device mounted on said robot
hand and one for a visual sensor device mounted fixedly

on a base on which said robot is installed. **0161417**

4.   A robot system as claimed in Claim 1, wherein said co-ordinates transformation parameters are determined by a matrix.

5.   A robot system as claimed in Claim 1, wherein said first co-ordinates system is established in said robot hand, and after an information in said second co-ordinates system is transformed into an information in said first co-ordinates system, said transformed information is further transformed into an information in a co-ordinates system of said robot body.

6.   A robot system as claimed in Claim 1, wherein said parameter measuring means comprises:

        first means for moving said robot to a fixed point on the fixed object to be measured with said robot being kept in a constant position and posture, and for calculating a position and posture of said robot hand moved said fixed point,

        second means for measuring a position and posture of said fixed point with a visual sensor device, and

        third means for calculating co-ordinates transformation parameters by means of data obtained by said first means and of data obtained by said second means.

7.   A robot system as claimed in Claim 6, wherein said visual sensor device includes a wrist visual sensor device mounted on said robot hand.

8.   A robot system as claimed in Claim 1, wherein

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said parameter measuring means comprises:

first means for moving said robot to a commanded position and for calculating a position and posture in said commanded position,

second means for measuring a position and posture of said robot after movement through said visual sensor device, and

third means for calculating co-ordinates transformation parameters by means of said calculation result obtained by said first means and of said measurement result obtained by said second means.

9. A robot system as claimed in Claim 8, wherein said visual sensor device includes a stationary visual sensor device fixed to a base on which said robot is installed.

10. A co-ordinates system correction apparatus comprising:

a robot having a first co-ordinates system provided in at least one of a robot body and a robot hand;

a visual sensor device mounted on a distal end portion of said robot or a base on which said robot is installed, said visual sensor device having a second co-ordinates system and a function for measuring a position and/or a posture of an object;

visual data storing means for storing a position and/or a posture information measured by said visual sensor device,

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robot data storing means for storing data representing a position and/or a posture of said robot in said first co-ordinates system when said visual data are measured;

parameter measuring means for measuring parameters giving a relationship between said first co-ordinates system and said second co-ordinates system by means of said visual data storing means and said robot data storing means;

parameter storing means for storing said measured parameters; and

means for transforming an information of a position and/or a posture of an object in said second co-ordinates system into an information in said first co-ordinates system by using said parameters.

11.   A method for correcting a robot visual sensor co-ordinates system for a robot system including a robot, a stationary visual sensor device fixed close to said robot, an image processor for processing image data from said sensor device, an error calculating device and a robot control unit for controlling and processing said components and data, said method comprising the steps of:

moving said robot to a commanded position under a control of said robot control unit,

measuring a position and posture of said robot in a stationary visual sensor co-ordinates system by means of said stationary visual sensor device and said image processor after movement of said robot,

calculating a commanded position and posture of said robot in said stationary visual sensor co-ordinates system by means of said error calculating device,

calculating errors in mounting said stationary visual sensor device from a deviation between said calculated and said measured position and posture of said robot, and

correcting the deviation between a robot co-ordinates system and said stationary visual sensor co-ordinates system, which caused by said mounting errors.

12.   A method for correcting a robot wrist visual sensor co-ordinates system for a robot system including a robot, a sensor device mounted on a robot wrist, an image processor for processing image data from said wrist sensor device, a mounting error measuring device and a robot control unit for controlling and processing said components and data, said method comprising the steps of:

moving said robot to a commanded point close to a fixed point of a stationary object to be measured. fixed in a constant position and posture under a control of said robot control unit,

calculating a position and posture of said robot hand,

measuring a position and posture of said fixed point in a robot wrist visual sensor co-ordinates system

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by means of said robot wrist visual sensor device and said
image processor,

calculating mounting errors of said robot wrist
visual sensor from said measured and said calculated
position and posture of said robot wrist by means of said
mounting error calculating device, and

correcting a deviation between said robot wrist
co-ordinates system and said robot wrist visual sensor
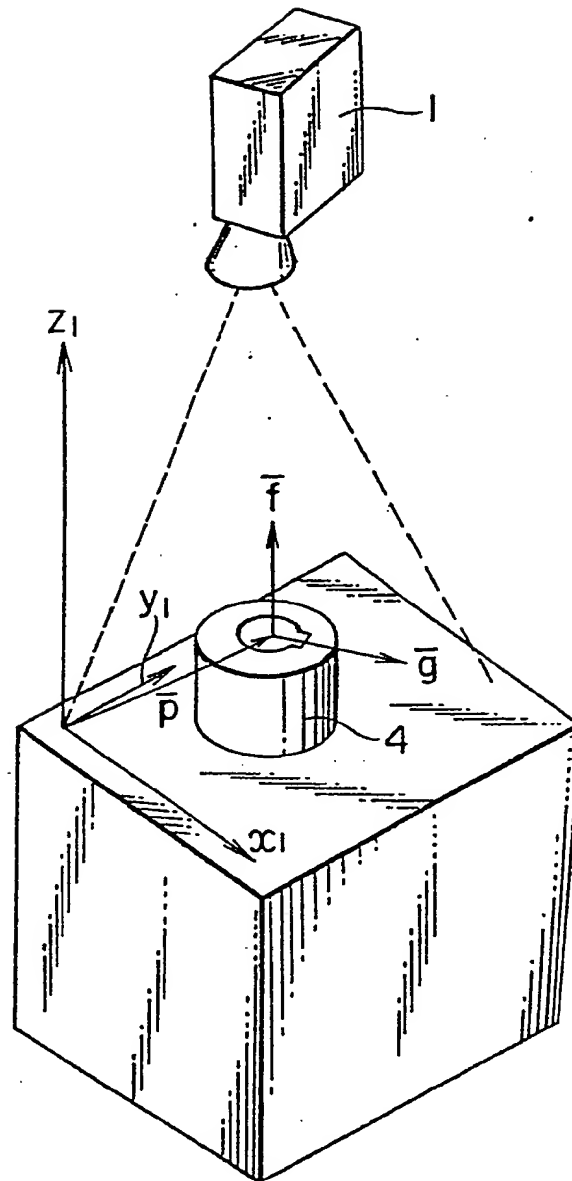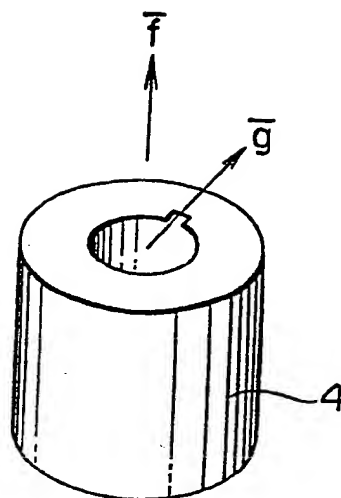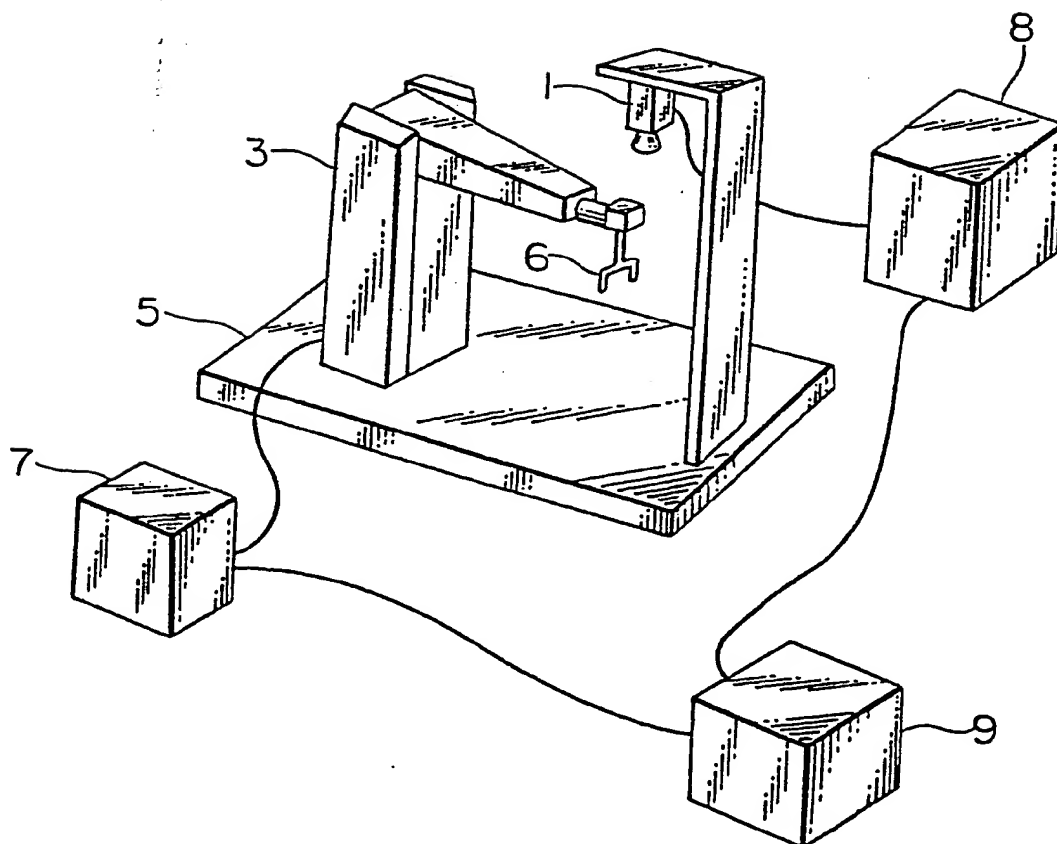co-ordinates system.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

$\overrightarrow{Zv}$ yv

xv

Ov

$\overrightarrow{ZR}$

5

O_R $\overrightarrow{y_R}$

$\overrightarrow{x_R}$

FIG. 6

$\overrightarrow{Z_R}$

O_R $\overrightarrow{y_R}$

$\overrightarrow{x_R}$

Zv

$\overrightarrow{L}$ γ

$\overrightarrow{y_U}$

O_U β

α

$\overrightarrow{x_U}$

FIG. 7

MOVE ROBOT TO A DESIRED POSITION $\underline{X}$ AND POSTURE $\overline{f}$ 101

IMAGE INPUT 102

MEASURE POSITION $\underline{X''}$ AND POSTURE $\overline{f''}$ OF ROBOT VIEWED FROM STATIONARY SENSOR 103

OBTAIN CALCULATED POSITION $\underline{X'}$ AND POSTURE $\overline{f'}$ OF ROBOT IN STATIONARY SENSOR CO-ORDINATES SYSTEM 104

CALCULATE PARAMETER ERRORS FROM DEVIATIONS BETWEEN $\underline{X'}$ AND $\underline{X''}$, AND BETWEEN $\overline{f'}$ AND $\overline{f''}$ 105

CORRECT PARAMETERS ON THE BASIS OF CALCULATED PARAMETER ERRORS 106

FIG. 8

FIG. 9

FIG. 10

FIG. 17

8/8

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8 —

POSITION $\overrightarrow{X'}$ AND NORMAL VECTOR $\overrightarrow{t'}$ OF THE FIXED POINT ON OBJECT ARE MEASURED IN WRIST VISUAL SENSOR CO-ORDINATES SYSTEM

203 —

202 —

IMAGE INPUT

7 —

MOVE ROBOT CLOSE TO THE FIXED POINT ON OBJECT

201 —

CALCULATE HAND POSITION AND POSTURE

205 —

209 —

CORRECT PARAMETERS ON THE BASIS OF CALCULATED PARAMETER ERRORS

9 —

204 —

INPUT POSITION AND POSTURE OF THE FIXED POINT ON THE OBJECT IN ADVANCE.

206 —

CALCULATE POSITION AND POSTURE OF THE FIXED POINT ON THE OBJECT AS VIEWED THROUGH WRIST VISUAL SENSOR CO-ORDINATES SYSTEM

207 —

CALCULATE MATRIX G

208 —

CALCULATE PARAMETER ERRORS

European Patent
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EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
A	MINI-MICRO SYSTEMS, vol. 17, no. 9, July 1984, pages 127-135, Denver, Colorado, US; D. EDSON: "Vision systems for bin-picking robots increase manufacturing options" * Pages 127-135 *	1	
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TECHNICAL FIELDS
SEARCHED (Int Cl 4)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26-04-1985	RESSENAAR J.P.

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
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The present search report has been drawn up for all claims

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THE HAGUE	26-04-1985	RESSENAAR J.P.

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